J.P. CARRARA & SONS, INC.

PRECAST/PRESTRESSED CONCRETE PRODUCTS

REQUEST FOR INFORMATION

TO: Arte St. Onge	FROM: Mike Davis
COMPANY: A.L. St. Onge Contractor, Inc.	DATE: 2/5/16
FAX NUMBER: 802-326-4006	TOTAL NO. OF PAGES INCLUDING COVER: 24
PHONE NUMBER: 802-326-4762	SENDER'S REFERENCE NUMBER: **RFI # 2**
RE: **Route 100 Bridge #177** **Waitsfield, VT**	CC:

X URGENT X FOR REVIEW X PLEASE COMMENT ☐ PLEASE REPLY ☐ FOR YOUR USE

PLEASE PROVIDE AND/OR CLARIFY THE FOLLOWING:

RFI #2: Seven Day Wet Cure on SIP Panels

Reference General Notes Item #11 on Sheet F1 – T.Y. LIN Comments of 2/3/16

We are asking for relief on the 7 day wet cure after de-tensioning requirement asked for in T.Y. LIN "approved as noted" comments dated 2/3/16.

Please see attached RFI of 3/18/15 and VTAOT response of 3/26/15 by Jeremy Reed.

If you have any questions, feel free to contact me.

Mike Davis

Subject: FW: JP Carrara RFI for precast/prestress concrete curing duration
Attachments: VAOT Precast Curing RFI.pdf

From: Reed, Jeremy [mailto:Jeremy.Reed@state.vt.us]
Sent: Thursday, March 26, 2015 9:44 AM
To: Ben Cota <bcota@jpcarrara.com>; Wild, Jim <Jim.Wild@state.vt.us>
Cc: Mike Davis <mdavis@jpcarrara.com>; Joe Carrara <jcarrara@jpcarrara.com>; PJ Carrara <pjcarrara@jpcarrara.com>; Williams, Chris <chris.williams@state.vt.us>; Lacroix, James <James.Lacroix@state.vt.us>
Subject: RE: JP Carrara RFI for precast/prestress concrete curing duration

Ben,
Since the RFI from JP Carrera, dated March 18, 2015 will impact so many projects, VTrans management will formally respond next week. In the interest of protecting the project schedules currently under production I will provide a synopsis of what the formal response will contain.

VTrans has decided to allow JP Carrera to proceed as requested in the RFI for the projects under construction during the 2015 construction year. We will re-evaluate the specification and curing requirements for future projects at a later date. Please continue fabrication using industry practices as specified in the RFI.

Thank You,
Jeremy Reed,
Construction Section,
Vermont Agency of Transportation

From: Ben Cota [mailto:bcota@jpcarrara.com]
Sent: Wednesday, March 18, 2015 1:06 PM
To: Wild, Jim; Reed, Jeremy
Cc: Mike Davis; Joe Carrara; PJ Carrara
Subject: JP Carrara RFI for precast/prestress concrete curing duration

Good Afternoon, Gentlemen –

Find attached RFI and supporting documentation requesting amendment to the precast & prestressed concrete curing duration.

Best Regards,

Benjamin L. Cota
Precast Production Engineer
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J.P. CARRARA & SONS, INC.

PRECAST/PRESTRESSED CONCRETE PRODUCTS

REQUEST FOR INFORMATION

TO: VAOT	FROM: Joe Carrara
COMPANY:	DATE: MARCH 18, 2015
FAX NUMBER	TOTAL NO. OF PAGES INCLUDING COVER: 21
PHONE NUMBER:	SENDER'S REFERENCE NUMBER: **RFI #**
RE: VAOT Concrete Curing Requirements	CC: -

☑ URGENT ☐ FOR REVIEW ☑ PLEASE COMMENT ☑ PLEASE REPLY ☐ FOR YOUR USE

PLEASE PROVIDE AND/OR CLARIFY THE FOLLOWING:

PRECAST/PRESTRESSED CONCRETE CURING REQUIREMENTS

Subsection 510.10(a) states that prestressed units shall be wet cured for seven (7) days after detensioning. Additionally, Subsection 540.08(a)(1) states that precast components shall be cured per the methods described in Subsection 501.17 until design strength is achieved.

JPC requests that the moist curing stipulations of 510.10(a) and 540.08(a)(1) continue to be substituted in favor of the standards set forth in the ACI and PCI documents referenced below.

Proper curing of precast concrete is crucial for the development of the required strength and durability characteristics as well as to inhibit shrinkage cracking associated with rapid moisture loss. The attached excerpts from PCI MNL 116 (Manual for Quality Control of Structural Precast Concrete Products) and ACI 308 (Guide to Curing Concrete) discuss the necessary curing duration to ensure achievement of these properties. Additionally, Michael Culmo of CME Associates prepared the attached document summarizing the benefits of prefabrication for accelerated bridge construction. More specifically, the document discusses the PCI recommendation that cure times be limited to as little as one (1) day.

The justification for reducing the curing duration of precast/prestressed concrete is contingent upon characteristics of the concrete mix design and curing environment. Specifically, the use of high early strength cement, extremely low water-cement ratio, and optimal curing environments used for precast concrete promote rapid achievement of the strength and durability properties. Additionally, the technological advancements in high range water reducing admixture effectiveness has made it possible to achieve the required properties so quickly that the benefit of an extended curing period is negligible. Concrete mix designs with water-cement ratios below 0.40 yield a very dense microstructure free of large capillary pores that harbor excess water not consumed in the hydration process. This significantly reduces the amount of shrinkage associated with drying because there isn't any excess moisture available to evaporate and cause volume change.

ACI 308 Guide to Curing Concrete Table 2.1 recommends a minimum curing period of three (3) days when Type III cement is utilized. However, the document goes on to explain that the minimum does not apply to accelerated curing conditions and that certain cement and admixture combinations are likely to reduce the required duration. Subsection 2.9.1 states that, "curing should be continued long enough to ensure that 100% of the specified value for concrete properties will be developed in a reasonable time period after deliberate curing measures have been terminated". The document then goes on to state that, "termination of the deliberate curing at some time short of full development of desired properties may be reasonable when based on experience with a given concrete mixture in a given environment" and that, "it is common to maintain curing measures until a minimum of 70% of the specified 28-day strength f'c has been achieved."

PCI MNL 116 Subsection 4.18.3 states that "curing shall be performed until the stripping strength as indicated on the production drawings has been achieved". This is consistent with the ACI 308 guidelines in that stripping and stress transfer strength requirements are typically greater than 70% f'c. Subsection 4.20 also states that, "moisture retention enclosures shall remain in place until the completion of the curing cycle". The document identifies the "curing cycle" as the period of time required to achieve the specified strength for transfer of prestress or stripping of forms and handling of product.

All of the VAOT approved precast concrete mix designs utilized by JPC have water-cement ratios below 0.35. The benefits of the low water-cement ratio are realized in the properties identified below:

- Compressive strength is designed for next day stress transfer and/or stripping which results in 28-day strengths well above the required design strength. Test cylinders representing precast/prestressed products cured by moisture retention without supplemental heat for 16 – 22 hours are consistently achieving design strength of 5,000psi within 48 hours. The corresponding 28-day strengths average greater than 8,000psi. Higher design strength (8,000 – 10,000psi) prestressed products that experience accelerated curing via live steam or radiant heat for 16 – 22 hours are consistently achieving design strength in 3-7 days. The corresponding 28-day strengths average greater than 9,700psi and 11,600psi respectively.

- Permeability of the lowest cement content (highest water-cement ratio) approved mix is 1,049 coulombs. The threshold of acceptability is nearly double (2,000 coulombs).
- When a proper moisture retaining enclosure is employed during the curing period prior to achievement of prestress transfer or stripping strengths no shrinkage cracking has been observed.

Unintentional consequences of the 510.10(a) and 540.08(a)(1) curing requirements:

- The geometry of many structural components, NEXT beams for example, makes it nearly impossible to moist cure the entire exposed surface after the product has been removed from the form. Production delays associated with leaving products in the forms for the specified time periods cannot be absorbed without compromising project schedules.
- Specifically during cold weather production, indoor storage space is at a premium and storing product in locations where moist curing can be performed for the specified time periods would significantly limit the production capacity of the plant.
- The costs, both monetary and schedule related, associated with the specified curing durations far outweigh the perceived benefits. In experience, the actual benefit does not exist because no issues as a result of improper curing have occurred.
- Prolonged curing durations have not been enforced in recent years, thus the costs associated with them have not been realized in current product pricing. Ultimately, enforcement of the specification will result in significant price increases and the inability of JPC to provide the recent volume of production.

Based on production experience and performance history of JPC approved precast mix designs, JPC requests that the moist curing stipulations of 510.10(a) and 540.08(a)(1) continue to be substituted in favor of the standards set forth in the referenced ACI and PCI documents. All temperature requirements shall be maintained.

Please contact us at 802-388-6363 with any questions or if further clarification is required.

construction operations such as form and shore removal, or the introduction of construction or service loads. When rate of strength development is critical in cold weather, it may be necessary to increase the curing temperature on the basis of tests with the specific concrete mixture. In-place tests may be necessary.

2.6.4 *Removal of cold-weather protection*—When water curing is used, either by retention or application of water, and the ambient air temperature is or will be below freezing, the concrete should be allowed to dry for at least 12 h before discontinuing or removing the temperature protection to minimize the likelihood of a nearly saturated surface condition when the concrete is exposed to freezing temperatures. Otherwise, a moist and perhaps warm concrete surface can be rapidly cooled and dried, resulting in freezing and, in some cases, cracking. Therefore, cold-weather curing coverings should be removed in stages to slow the rates of cooling and drying.

2.7—Hot-weather protection and curing

Hot weather can include warm, humid environments like summer along the Gulf of Mexico or within large river valleys that can be relatively benign in regard to concrete curing, or the more hostile warm and dry environments like arid regions of the west or southwest U.S. In these dry environments, it is critical to maintain adequate moisture content in the concrete, and under such conditions, the added curing water itself can evaporate so quickly that it requires constant replacement. This is complicated by the limited availability of curing water in such environments.

Hot weather is defined as any combination of high air temperature, low relative humidity, and wind velocity that impairs the quality of fresh or hardened concrete, or otherwise results in undesirable concrete properties. Because hot weather can lead to rapid drying of concrete, protection and curing are critical. Additional information about curing concrete in hot weather is contained in ACI 305R.

Hot-weather curing starts before the concrete is placed, with steps taken to ensure that the subgrade, adjacent concrete, or formwork do not absorb water from the freshly placed concrete. This problem can be minimized by spraying the formwork, existing concrete, reinforcement, and subgrade with water before placement, which can also lower the temperature of those surfaces. Quality-control measures should be used to avoid standing or ponded water on these surfaces while placing the concrete.

During hot weather, initial curing methods should be used immediately after placing, and before and during the finishing process. Steps for initial curing should be taken to slow the evaporation of the bleed water or to replenish the bleed water. Evaporation rate is reduced by windscreens or sunscreens that block wind and radiant energy, and by fogging that temporarily increases the humidity of the air above the concrete. Some of the fog droplets fall to the concrete surface and augment the bleed water. Training, judgment, and quality-control measures are required to replace the evaporated bleed water. At no time is it proper to mix surface water with the top layer of cement paste in subsequent finishing operations. Mixing of water into the paste increases the *w/cm* at the surface, reducing strength and durability in this critical portion of the concrete. When high temperatures with wind, low humidity, or both, prevail, an evaporation-reducing film may need to be applied one or more times during the finishing operation to reduce the risk of plastic shrinkage cracking and crusting (Section 2.3.2).

Final curing methods can be used once the concrete surface will not be damaged by the application of curing materials or water. The need for continuous curing is greatest during the first few days after placement of the concrete in hot weather. During hot weather, provided that favorable moisture conditions are continuously maintained, concrete can attain a high degree of maturity in a short time. Water-curing, if used, should be continuous to avoid volume changes due to alternate wetting and drying. Liquid membrane-forming compounds with white (Type II) pigments should be used to reflect solar radiation.

2.8—Accelerated curing

A variety of proprietary products and specialized curing procedures have been developed to rapidly cure concrete products. These include insulating the concrete to accelerate curing by retaining heat of hydration or the addition of heat via steam or other methods. Such procedures, alone or in combination, are used to reduce the total time required for the concrete to achieve sufficient strength to permit handling. High-temperature, high-pressure, or steam curing are beyond the scope of this document. See Pfeifer and Marusin (1982), Heinz and Ludwig (1987), and Kelham (1996).

2.9—Minimum curing requirements

2.9.1 *General*—Curing should be continued long enough to ensure that 100% of the specified value for concrete properties will be developed in a reasonable time period after deliberate curing measures have been terminated, especially for mechanical properties such as strength or modulus of elasticity, and for durability-related properties, such as low permeability, abrasion or scaling resistance, initial surface absorption, or resistance to freezing and thawing. After curing measures are terminated and the concrete is fully exposed to the natural environment, the rate at which mechanical- or durability-related properties continue to develop could be reduced significantly. In the case of concrete properties in the curing-affected zone, further development may cease altogether upon drying of the near surface. For these reasons, it is always best to maintain deliberate curing until the desired in-place properties have been achieved. Termination of deliberate curing at some time short of full development of desired properties may be reasonable when based on experience with a given concrete mixture in a given environment. Thus, when strength is the essential performance criterion, it is common to maintain curing measures until a minimum of 70% of the specified 28-day strength f'_c, has been achieved (ACI 301). When the structure's performance requires that the in-place strength or other concrete property reaches 100% of the specified value, curing should be extended until tests prove that the specified property has been reached. The temperature and moisture content of small, field-cured cylinders can differ significantly from that of the larger concrete placement that they are meant to represent, however. The in-place strength can be verified by tests such as penetration resistance (ASTM C 803), pullout tests (ASTM C 900), maturity measurement (ASTM C 1074), or tests of cast-in-place cylinder specimens (ASTM C 873). Also refer to ACI 228.1R for procedures to implement these in-place tests.

When performance criteria, such as surface hardness, abrasion resistance, resistance to freezing and thawing, surface absorption, or permeability are required, curing may need to be extended until the required values for such properties are achieved. It may be necessary to perform laboratory tests to evaluate the effect of curing on various concrete properties. Useful standard tests for this purpose may include C 666, C 642, C 1151, C 1202, C 944, C 418, C 779, and C 1138. (See also Liu [1994].) In-place tests for surface penetrability are discussed in 228.2R and in Chapter 4 of this document.

2.9.2 *Factors influencing required duration of curing*—The duration of curing required to achieve the desired levels of strength, durability, or both, depends on the chemical composition and fineness of the cementitious materials, *w/cm*, mixture proportions, aggregate characteristics, chemical and mineral admixtures, the temperature of the concrete, and the effectiveness of the curing method in retaining moisture in the concrete. This complex set of factors makes it difficult to confidently state the minimum curing time required to achieve the desired level of performance with the particular mixture in question. For concrete with and without pozzolans and chemical admixtures, a 7-day minimum duration of curing will often be sufficient to attain approximately 70% of the specified compressive strength. It is not necessarily true, however, that durability characteristics, such as abrasion resistance or surface absorption, will reach satisfactory levels in the same minimum time. Certain cement and admixture combinations, and high temperature are likely to reduce the time required to less than 7 days, while other combinations of materials, cooler concrete temperatures, or both, will extend the time required.

In general, when the development of a given strength or durability is critical to the performance of the concrete during construction or in service, the minimum duration of curing should be established on the basis of tests of the required properties performed with the concrete mixture in question. It is the responsibility of the designer and specifier to determine which properties are critical to the performance of the concrete under the intended service conditions and to develop a testing program to verify that the curing has been maintained long enough so that such properties have been achieved.

When natural weather conditions of temperature, humidity, and precipitation combine to cause zero net evaporation from the surface of the concrete, no curing measures are required to maintain adequate moisture content for as long as those natural conditions remain. In most climates, however, such conditions can change hourly, or daily, and rarely persist for the time required to foster development of the required concrete properties. It is therefore necessary to take steps to protect the concrete against loss of moisture. When no data are available from experience, values are not specified for concrete strength or durability, and when testing is not performed to verify in-place strength, concrete should be maintained above 10 C (50 F) and kept moist for the minimum curing periods shown in Table 2.1. Table 2.1 is not intended to apply to accelerated curing under high temperature, high pressure, or both.

Table 2.1—Recommended minimum duration of curing for concrete mixtures*

	Minimum curing period
ASTM C 150 Type I	7 days
ASTM C 150 Type II	10 days
ASTM C 150 Type III or when accelerators are used to achieve results demonstrated by test to be comparable to those achieved using ASTM C 150 Type III cement	3 days
ASTM C 150 Type IV or Type V cement	14 days
Blended cement, combinations of cement and other cementitious materials of various types in various proportions in accordance with ASTM C 595, C 845, and C 1157	Variable. See section 2.9.

*with various cement types when no testing is performed and no concrete properties are specified

CHAPTER 3—CURING FOR DIFFERENT TYPES OF CONSTRUCTION

3.1—Pavements and other slabs on ground

3.1.1 *General*—Slabs on ground include highway pavements, airfield pavements, canal linings, parking lots, driveways, walkways, and floors. Slabs have a high ratio of exposed surface area to volume of concrete. Without preventive measures, the early loss of moisture due to evaporation from the concrete surface could be so large and rapid as to result in plastic shrinkage cracking. Continued loss of moisture, and the accompanying decrease in the degree of hydration, would have a deleterious effect on strength, abrasion resistance, and durability. When moisture loss is predominantly at the top surface of the concrete, the gradient in moisture content leads to greater shrinkage at the top than at the bottom, which in turn leads to an upwards curling of the slab (Ytterberg 1987a,b,c). Alternatively, moisture can be lost from the bottom surface due to absorption into a dry subgrade, causing the opposite moisture gradient if the top surface is kept moist. This also leads to distortion of the slab. To minimize the development of such gradients in moisture content, both the top and bottom of slabs on ground should be uniformly moist or uniformly dry. Uniformly moist conditions are usually required if the properties of the concrete surface are important for the performance or appearance of the slab. This is achieved by prewetting the subgrade, and minimizing moisture loss at the top surface through initial, intermediate, and final curing as described in Chapter 1. Similarly, when an impervious membrane or vapor barrier is installed below the slab, maintaining the top surface in a moist condition is imperative to minimize curling. Placement of a 100 mm (4 in.) compacted, drainable fill on top of membranes and vapor retarders helps to dry the bottom of the slab so that curling is reduced while both the top and bottom surfaces dry (ACI 302.1R). The final tendency for distortion of the slab due to differential volume change, however, will depend on the moisture gradient after curing measures have been terminated.

3.1.2 *Curing procedures*—To maintain a satisfactory moisture content and temperature, the entire surface of the newly placed concrete should be treated in accordance with one of the water-curing methods (Section 2.2), one of the curing material methods (Section 2.4.2), or a combination thereof, beginning as soon as possible after finishing operations, without marring the surface.

To avoid plastic-shrinkage cracks, protective measures such as sun shields, wind breaks, evaporation reducers, or fog spraying should be initiated immediately to reduce evaporation. Exposed surfaces of the slab should be entirely covered and kept wet until the required concrete properties have developed to the desired level.

Mats used for curing can either be left in place and kept saturated for completion of the curing, or can be subsequently replaced by a liquid membrane-forming curing compound, plastic sheeting, reinforced paper, straw, or water. If the concrete has been kept continuously moist since casting and finishing, drying of the concrete with its accompanying shrinkage can begin only when the curing procedures are discontinued. Therefore, the surface should be protected against rapid loss of moisture upon the termination of curing by replacing wet burlap with plastic sheets until the surface has dried under the sheets.

3.1.3 *Duration of curing*—When the average ambient daily temperature (computed as the average of the highest and lowest temperature from midnight to midnight) is above 5 C (40 F), the recommended minimum period of maintenance of moisture and temperature for all procedures is as shown in Table 2.1 (Section 2.9.2) or it is the time necessary to attain an in-place compressive strength of the concrete of at least 70% of the specified compressive or flexural strength, whichever period is longer. If testing is not performed to verify in-place strength, concrete should be maintained above 10 C (50 F) and kept moist for the time periods shown in Table 2.1, unless otherwise directed in the specifications. Strength-based criteria should be replaced or augmented with durability-related criteria when appropriate. When concrete is placed at an average daily temperature of 5 C (40 F) or lower, precautions should be taken to prevent damage by freezing as recommended in ACI 306R. These general-purpose recommendations can be insufficient if durability-related surface properties are required.

3.2—Buildings, bridges, and other structures

3.2.1 *General*—Concrete in structures and buildings includes cast-in-place walls, columns, slabs, beams, and all other portions of buildings except slabs-on-grade, that are covered in Section 3.1. It also includes small footings, piers, retaining walls, tunnel linings, and conduits. Not included are mass concrete (see Section 3.3), precast concrete, and other constructions as discussed in Section 3.4.

3.2.2 *Curing procedures*—Under usual placing conditions, curing should be accomplished by one or a combination of methods discussed in Chapters 1 and 2.

Additional curing should be provided after the removal of forms when the surface strength or durability of underside surfaces is deemed important, or when it is necessary to minimize dusting. Additional curing is done by either applying a liquid membrane-forming curing compound or by promptly applying sufficient water to keep the surface continuously moist. Water curing of vertical surfaces can be done by using wet burlap covered with polyethylene. Water curing of the bottom of slabs and beams is not recommended and is rarely effective. Form removal should be done when curing has been sufficient.

After the concrete has hardened and while the forms are still in place on vertical and other formed surfaces, form ties may be loosened when damage to the concrete will not occur and water applied to run down on the inside of the form to keep the concrete wet. Care should be taken to prevent thermal shock and cracks when using water that is significantly cooler than the concrete surface. Curing water should not be more than about 11 C (20 F) cooler than the concrete (Section 2.2.1). Immediately following form removal, the surfaces should be kept continuously wet by a water spray or water-saturated fabric or until the membrane-forming curing compound is applied. Curing measures should include treatment of top surfaces.

3.2.3 *Duration of curing*—When the daily mean ambient temperature is above 5 C (40 F), curing should be continuous for the time periods shown in Table 2.1, or for the time necessary to attain a minimum of 70% of specified compressive (or flexural strength if appropriate), whichever period is longer. If concrete is placed with daily mean ambient temperatures at 5 C (40 F) or lower, precautions should be taken as recommended in ACI 306R. Strength-based criteria should be replaced or augmented with durability-related criteria when appropriate (See Section 2.9.1 and Chapter 4).

3.3—Mass concrete

3.3.1 *General*—Mass concrete is any volume of cast-in-place concrete with dimensions large enough to require measures be taken to cope with the generation of heat and attendant volume change and to minimize cracking. It is most frequently encountered in piers, abutments, dams, heavy footings, and similar massive constructions; although, the impact of temperature rise and thermal gradients should be considered in all concrete, whether the concrete is reinforced or not. Such problems are exacerbated where high strength and high cementitious materials contents are required. Recommendations for the control of temperature and thermal gradients in mass concrete are found in ACI 207.1R and ACI 207.2R.

3.3.2 *Methods and duration of curing*—Mass concrete is often cured with water for the additional cooling benefit in warm weather; however, this can be counterproductive when the temperature gradient between the warmer interior and the cooler surface generates stress in the concrete. Horizontal or sloping unformed surfaces of mass concrete can be maintained continuously wet by water spraying, wet sand, or water-

Standard

Care shall be taken to ensure the proper distribution of vibration when vibrating tables are used. The number and location of external vibrators to be used on a vibrating table shall be determined on the basis of adequate amplitudes of vibration and uniform distribution over the entire concrete surface. The frequency and amplitude shall be checked at several points on the table, using a vibrograph, vibrating reed tachometer, or other suitable methods. The vibrators shall be positioned to ensure dead spots are eliminated and the most uniform vibration is attained.

4.18 Requirements for Curing Concrete

4.18.1 General

Freshly deposited and consolidated concrete shall be protected from premature drying and temperature extremes. Concrete shall be cured with a minimal moisture loss, and at a relatively constant temperature, for the period of time necessary to ensure proper hydration of the cement and hardening of the concrete. Curing procedures shall be well established and properly controlled to develop the required concrete quality and stripping or transfer strength. Curing procedures shall be designed to minimize plastic shrinkage cracking.

Protection of concrete surfaces against moisture loss to prevent shrinkage cracking of concrete that contains silica fume, metakaolin, or other pozzolans, shall begin immediately after finishing.

4.18.2 Curing Temperature Requirements

The concrete in the form shall be maintained at a temperature of not less than 50°F (10°C) during the curing period (prior to reaching stripping strength). The time between placing of concrete and the start of curing shall be minimized in hot or windy weather to prevent loss of moisture.

During the initial curing period, positive action shall be taken to provide heat, if necessary to maintain minimum

Commentary

Vibrating tables or casting decks are best used for flat or low-profile units, and provide an easy and effective method for application of external vibration.

The frequency and amplitude of vibrating forms and vibrating tables equipped with external vibrators should be determined at sufficient points to establish the level of uniformity.

C4.18 Requirements for Curing Concrete

C4.18.1 General

Determining the proper type of curing is dependent on variables such as the mass of the member, type and properties of cement, air temperature, humidity, and many other variables. The curing period of concrete is of significant interest in the production of precast concrete elements. It should begin during the early stages of strength development (at initial set) and continue until the concrete has reached a specified strength for stripping or stressing the member.

Proper curing involves maintaining a satisfactory moisture content and temperature in the concrete. Rapid moisture loss may result in reduced strength development and an increased potential for plastic shrinkage cracking. Accordingly, concrete surfaces should be protected to prevent rapid loss of moisture while the concrete is plastic.

ACI 308, *Standard Practice for Curing Concrete,* describes various curing procedures in detail.

C4.18.2 Curing Temperature Requirements

Except for special locations or climates with prolonged temperatures below 50°F (10°C), continued curing in storage yards should enable the units to reach final design strength. Rapid drying may result in plastic shrinkage cracking.

Retention of the heat released by the hydration of the cement can be used advantageously by precasters to

Standard

temperatures, and to prevent loss of moisture from the unit. Curing materials or methods shall not allow one portion of an element to cure differently than other portions of the element.

The maximum curing temperature shall not exceed 180°F (82°C).

4.18.3 Curing to Attain Specified Stripping or Transfer Strength

Curing shall be performed until the stripping strength as indicated on the production drawings has been achieved. The stripping strength and strength at transfer of prestress shall be set by the design engineer, based on the characteristics of the product. It shall be high enough to ensure that the stripping and transfer of prestress does not have a deleterious effect on the performance of the final product.

The stripping, transfer of prestress, or handling strength of the product shall be determined by test specimens cured under the same conditions as the product.

In addition to the standard test cylinders cured in accordance with ASTM requirements, additional test cylinders shall be made and cured similarly to the units for estimating critical shipping or erection strengths.

4.18.4 Monitoring of Concrete Curing Temperatures

Concrete elements cured using the application of heat (or solar radiation) to accelerate curing shall be monitored to assure that the minimum and maximum concrete temperatures, rates of heating, and the rate of cooling specified herein are not exceeded.

The selection of locations for concrete temperature monitoring shall be made to measure the likely maximum and minimum temperature or rate of temperature change.

Commentary

provide much of the heat for curing. Insulated tarpaulins are effectively used for a combination of moisture and heat retention. Differential curing of an element may produce differential shrinkage of the concrete, which can lead to warping of the element.

C4.18.3 Curing to Attain Specified Stripping or Transfer Strength

Stripping or prestress transfer strengths are typically specified at a minimum of 2000 psi (13.8 MPa) for non-prestressed units and 3000 psi (20.7 MPa) or greater for prestressed units. Specified release strengths higher than this may require special mix designs, special curing provisions or longer curing cycles.

Well documented and correlated methods using concrete maturity (time and temperature relationships) have proven to be beneficial in refining curing procedures and more accurately predicting when the required stripping strength has been achieved.

Due to the difference in mass between standard test specimens and the actual product, curing "under the same conditions" usually requires that the test specimens be protected from moisture loss and rapid temperature variations. Accordingly, the temperature of the specimens should be closely monitored.

C4.18.4 Monitoring of Concrete Curing Temperatures

Careful monitoring of concrete curing temperatures, and correlation with respect to stripping or release strengths, can be effectively used to optimize the curing cycle.

Temperature monitoring locations should be based on the location of heating or cooling sources, the configuration and design of the form and insulating enclosure, and the cross-sectional dimensions and configuration of the product. Reference Article 2.2.6 for additional information.

Standard

4.19 Accelerated Curing of Concrete

419.1 General

Accelerated curing procedures shall be developed to optimize the concrete strength development while ensuring the long-term durability of the concrete.

Temperature guidelines for accelerated curing are as follows:

1. The controlling temperatures shall be those actually achieved within the concrete elements, not ambient temperatures of the curing area.
2. Accelerated curing shall be started after the concrete has attained initial set, determined in accordance with ASTM C403, *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance,* except as noted herein. A strength gain of 500 psi (3.4 MPa) indicates the concrete has attained initial set.

Commentary

C4.19 Accelerated Curing of Concrete

C4.19.1 General

Accelerated curing is an important aspect of many precast concrete operations, which rely on a daily production cycle for ensuring economical production.

For new concrete mix designs or accelerated curing procedures, a comparison should be made between test specimens that are subject to the same initial curing conditions as the product followed by "final curing" per ASTM C31, and specimens that receive "standard curing" in accordance with ASTM C31. The 28-day strength of the specimens representing the product receiving accelerated curing should not be less than 90% of the strength of the "standard cured" specimens at the same age.

1. Curing procedures should be confirmed on an experimental basis. This is to ensure that the heat application rate limitations or the maximum temperature allowances given herein are not exceeded. The appropriate application of heat is fundamental to keeping the total curing time within a daily production period.
2. After placing, consolidation, and finishing, the concrete should be allowed to attain initial set before heat is applied that will raise the concrete temperature above 104°F (40°C); otherwise, the elevated temperature may have a detrimental effect on the long-term strength and durability of the concrete.

   The time to initial set (preset period) is typically in the range of 3 to 8 hours after batching. The length of the preset period is dependent on factors such as the type of cement, use of admixtures, w/cm, temperature, and other mix characteristics. Because of the wide possible variation of initial set times, determination of the actual initial set time per ASTM C403 is very important.

   For a given concrete mix design, the preset period may be established from test data at various initial concrete temperatures. A minimum of three ASTM C403 time of setting test results should be plotted on a temperature-time graph. It is preferable to use test data

Standard / Commentary

obtained at 10°F (6°C) intervals. The extreme data points should cover the anticipated range of concrete placement temperatures. The best fitting smooth curve is then drawn through the data points. To determine an appropriate preset time, plot the actual concrete placement temperature on the best-fit curve and find the associated time of initial set. The preset period determined from the graph should be rounded up to the next half-hour.

Any changes in the concrete mix components that are likely to affect the preset time should be considered cause for performing new ASTM C403 tests.

3. If necessary, the concrete temperature may be increased during the preset period at a rate not to exceed 10°F (5.6°C) per hour. The total permissible temperature gain during the preset period shall not exceed 40°F (22°C) higher than the placement temperature or 104°F (40°C), whichever is less.

3. These temperature restrictions apply when heat is supplied to the curing enclosure prior to initial set. Temperatures in excess of 104°F (40°C) are possible due to natural cement hydration without supplemental heating and are not prohibited.

If it is desired to raise the temperature of the concrete during the preset period, a better approach is to heat the concrete constituents, thus raising the temperature of the fresh concrete prior to placement. The maximum concrete temperature of 95°F (35°C) at time of placement should be observed as well as the 104°F (40°C) maximum allowed prior to initial set.

When the concrete temperature is increased by more than 10°F (5.6°C) over the placement temperature by applying heat during the preset period, a comparison shall be made between test specimens that are subject to the same initial curing conditions as the product followed by "final curing" per ASTM C31, and specimens that receive "standard curing" in accordance with ASTM C31. The 28-day strength of the specimens representing the product receiving preset curing shall not be less than 90% of the strength of the "standard cured" specimens at the same age.

Increasing the concrete temperature by more than 10°F (5.6°C) prior to initial set can result in a reduction of concrete strength and long-term durability. This provision requires that control test specimens be made to determine the effect on concrete properties.

"Standard curing" requires that test specimens be stored for up to 48 hours at a temperature range of 60° to 80°F (16° to 27°C), followed by moist curing at a temperature of 73 ± 3°F (23 ± 2°C) until tested. The companion specimens should be monitored to ensure the same accelerated curing conditions as the product they represent. When the product is removed from the form, these specimens should be placed in the same "final curing" environment as the control specimens, until tested.

4. For accelerated curing, heat shall be applied at a controlled rate following the preset period in combination with an effective method of supplying or retaining moisture.

4. The limitations on concrete temperature gain rate and the maximum permissible temperature above placement temperature during the preset period should be observed.

A heat gain not to exceed 36°F (20°C) per hour,

The rate of heat gain should not be greater than that

Standard

measured in the concrete, is acceptable provided the concrete has attained initial set in accordance with ASTM C403.

5. The maximum curing temperature shall not exceed 180°F (82°C). This temperature shall be measured at the portion of the unit that is likely to experience the maximum temperature during curing.

6. The maximum cooling rate from the sustained accelerated curing temperature shall be 50°F per hr (27.8°C per hr). In order to prevent surface crazing or other thermal related damage, the cooling at this rate shall continue until the concrete temperature is 40°F (22°C) or less above the ambient temperature outside the curing enclosure.

7. Self-recording thermometers shall be provided to show the time-temperature relationship for the entire curing period or until stripping or transfer of prestress. At least one recording thermometer, per contiguous form group and common heat source, shall be used to monitor the product at appropriate locations.

4.19.2 Curing with Live Steam

Steam curing shall be performed under a suitable enclosure to minimize moisture and heat loss. The curing enclosure shall allow free circulation of the steam. Steam jets shall be positioned to provide a uniform distribution of heat without discharging directly on the concrete, forms, or test cylinders.

Commentary

necessary to attain the minimum stripping and transfer strength in the required amount of time.

5. The maximum concrete temperature should not be greater than that necessary to attain the minimum stripping and transfer strength in the required amount of time. If a known potential for alkali-silica reaction or delayed ettringite formation exists, the maximum curing temperature should be reduced to 158°F (70°C). Higher curing temperatures, and exposure to moisture while in service, can increase the potential for these types of deleterious reactions. Increases in cement fineness, SO_3, and total equivalent alkali content above typical historical values, appear to be additional risk factors for such reactions.

6. Units should be allowed to cool gradually to prevent thermal shock, which may cause cracking. Additionally, when the concrete is warmer than the ambient conditions, there is a tendency for soluble salts (efflorescence) to migrate to the surface immediately after stripping.

7. To aid personnel who control the temperature during curing, it is recommended that the desired curing time-temperature relations be placed on the chart of the recording thermometer. With this information available, the desired temperature can be more easily maintained. Temperature monitoring should be performed at the coolest and hottest positions in the unit. Curing temperatures have increasingly detrimental effects on the concrete as the boiling point of water (212°F [100°C]) is approached. In addition to possible detrimental chemical changes in the concrete, the expansion of moist air or vapor in the pore spaces of the cement paste can cause damage that results in a loss of strength and durability.

C4.19.2 Curing with Live Steam

Monitoring techniques will require temperature checks at various points to effectively control curing temperatures.

Standard

4.19.3 Curing with Radiant Heat and Moisture

During the cycle of radiant heat curing, effective means shall be provided to prevent rapid loss of moisture in any part of the member.

4.20 Curing by Moisture Retention Without Supplemental Heat

4.20.1 General

For curing of the concrete without supplemental heat, the surface of the concrete shall be kept covered or moist until such time as the compressive strength of the concrete reaches the strength specified for transfer of prestress or stripping.

4.20.2 Moisture Retention Enclosures

Enclosures used for the purpose of retaining moisture during the curing period shall ensure that free water is present on all concrete surfaces at all times. Moisture retention enclosures shall be resistant to tearing and shall be positively fastened in place to avoid displacement by wind or other means during the curing cycle. Moisture retention enclosures shall remain in place until the completion of the curing cycle as described above.

Commentary

C4.19.3 Curing with Radiant Heat and Moisture

Moisture may be supplied by a cover of moist burlap, cotton mats, or other effective means. Moisture may be retained by covering the member with an impermeable sheet in combination with an insulating cover, or by applying a liquid seal coat or membrane-curing compound.

Radiant heat may be applied by circulating steam or hot liquids through pipes, electric blankets, heating elements, or by circulation of warm air. Heating devices should not be in direct contact with the concrete, forms, or test cylinders.

Due to the slow rise of ambient temperatures with radiant heat, application of the heat cycle may be accelerated to meet climatic conditions. In all cases, the curing procedure to be used should be well established and carefully controlled to meet the requirements outlined in Article 4.19.

C4.20 Curing by Moisture Retention Without Supplemental Heat

C4.20.1 General

Acceptable methods of curing are:

- Leave the unit in the forms and keep the top surfaces continuously moist by fogging, spraying, or covering with wet mats, or by covering the top surface with an impermeable cover or membrane curing compound.
- Remove the side forms and cure all exposed surfaces by the applicable methods described above.

C4.20.2 Moisture Retention Enclosures

Standard

4.20.3 Curing with Membrane Curing Compound

The use of membrane curing compound to retain moisture within the concrete during curing shall be as follows:

1. The coating of membrane curing compound shall cover the entire exposed surface with a uniform film. The coating shall remain in place without gaps or omissions until the full curing cycle is complete. Positive means shall be taken to detect and re-coat areas of incomplete coating.
2. The membrane curing compound shall be applied to the exposed concrete surface at the minimum coverage rate recommended by the manufacturer.
3. The membrane curing compound shall be applied as soon as the surface bleed water sheen disappears.
4. The membrane curing compound shall be compatible with coatings or other materials to be applied to the product in later construction stages.

4.21 Post-Tensioning Tendon Grout

4.21.1 Scope and Purpose

Grout for post-tensioning tendons used in prestressed concrete members shall provide protection of post-tensioning steel and develop bond between the prestressing steel and the surrounding concrete.

4.21.2 Materials for Post-Tensioning Tendon Grout

The materials used for making grout to be used in post-tensioning systems shall meet the following minimum requirements:

1. Portland cement shall be in accordance with ASTM C150. The cement shall be Types I, II or III.

2. Water used in the grout shall be potable, clean, and free of materials known to be deleterious to cement or cause corrosion of the prestressing steel.

Commentary

C4.20.3 Curing with Membrane Curing Compound

Curing compounds should only be used on surfaces where discoloration or staining will not result in an unsatisfactory product. Some curing compounds function as bond breakers and may interfere with adhesion of repairs or surface coverings such as paint, fabric, insulation materials, or other types of protective coatings. Curing compounds with bond-breaking characteristics should only be used if a definite bond break is required.

Membrane curing compounds should not be used in areas where joint sealants or other required adhesive materials are to be applied, unless entirely removed at the end of the curing period. Removal should be performed by sandblasting or with an approved solvent, unless conclusive test results demonstrate that the residue of the membrane does not reduce bond.

C4.21 Post-Tensioning Tendon Grout

C4.21.1 Scope and Purpose

Post-tensioning is sometimes used to supplement pretensioning in precast concrete units. It may be used to provide required prestress force in excess of stressing bed capacity, in construction of segmental elements, and in situations that require close control of camber.

C4.21.2 Materials for Post-Tensioning Tendon Grout

Type III cement is typically only used for cold weather grouting. When Type III cement is used, trial mixes should be performed to determine an appropriate mix design.

Admixtures may be used to reduce the water requirement and improve flowability at a given water content. While such admixtures are often used, research of horizontal tendons in semirigid ducts indicates that satisfactory grout quality may be achieved without admixtures.

UTAH Department of Transportation

Effects of Accelerated Bridge Construction and Prefabrication on Concrete Quality

1.0 Introduction

CME Associates is in the process of developing standards for accelerated bridge construction for the Utah Department of Transportation (UDOT). Part of this contract is to investigate the effects of accelerated bridge construction and prefabrication on the quality of concrete. This is a concise investigation with limited scope and effort. This subject may warrant a more significant study in the future. This report outlines our findings.

2.0 Concrete Cure Time

Curing of concrete is the process of maintaining satisfactory moisture and temperature within poured concrete immediately after placing and for a specified period of time so that the desired quality of concrete can be achieved. Moisture is required during curing so that the cement in the concrete can hydrate. Proper curing is a key component of concrete quality and durability. Improper curing can result in the following problems:

- Lower Concrete Strength:

  Moist curing ensures that the concrete hydrates and attains proper strength. If concrete is not properly moist cured (i.e. left in a dry condition), it will have a significant reduction in final compressive strength. Figure 2.1 shows the effect of cure time on concrete strength and concrete quality [1]. The chart uses a 7 day cure as a base line for comparison.

  A review of this chart shows that if a specimen is left to cure in air, the final strength is reduced by approximately 45 percent when compared to the 7 day cure. A three day moist cure improves the situation, but the final strength is still reduced by approximately 20 percent when compared to the 7 day cure. There is a more pronounced increase in strength for concrete cured for 180 days; however this amount of moist curing is impractical.

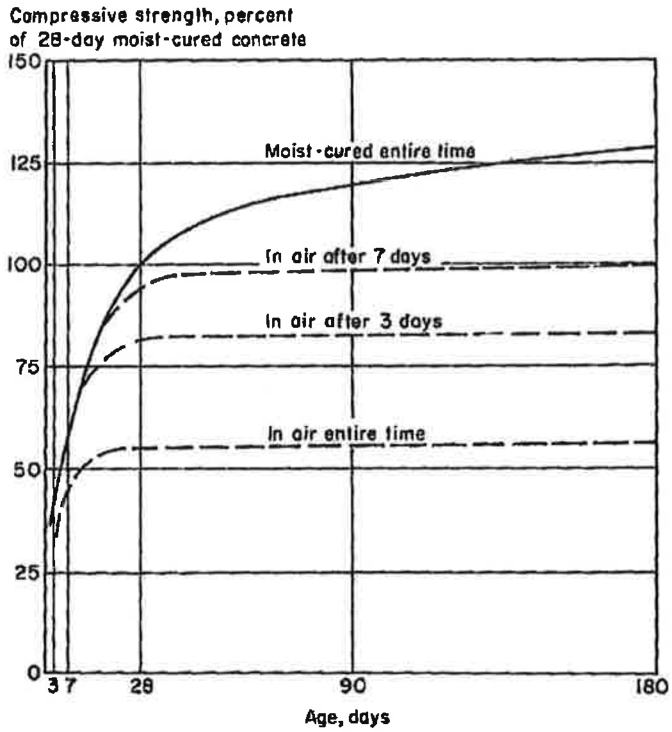

Fig. 10-1. Concrete strength increases with age as long as moisture and a favorable temperature are present for hydration of cement. Reference 10-16.

Figure 2.1

- Permeability:
  Permeability refers to the ability of concrete to resist the penetration of water or other substances (chloride ions, etc.). A concrete with low permeability is desired because it prevents the infiltration of water and other substances that can lead to concrete degradation and corrosion of the internal reinforcing steel. There are several factors that affect the permeability of concrete mixes. One of the factors is cure time. Figure 2.2 shows the effect of cure time on concrete strength based on tests of 4"x8" cylinders subjected to 3000 psi of water pressure [1].

  A review of this chart shows that concrete that is moist cured for 7 days has significantly lower permeability when compared to concrete that is only cured for 1 day. For example a concrete with a water cement ratio of 0.5 has a permeability of 5 cm/secx10^{-10}, while the same concrete cured for 7 days has a value that is approximately 1 cm/secx10^{-10}. This represents a reduction in permeability of 5 fold. Concretes with very low water/cement ratios exhibit very low permeability values regardless of cure time. It is normally impractical to place concrete with water/cement ratios as low as 0.4 in the field; however concrete can be placed at a water-cement ratio of less than 0.4 in a controlled environment such as a precast fabrication plant.

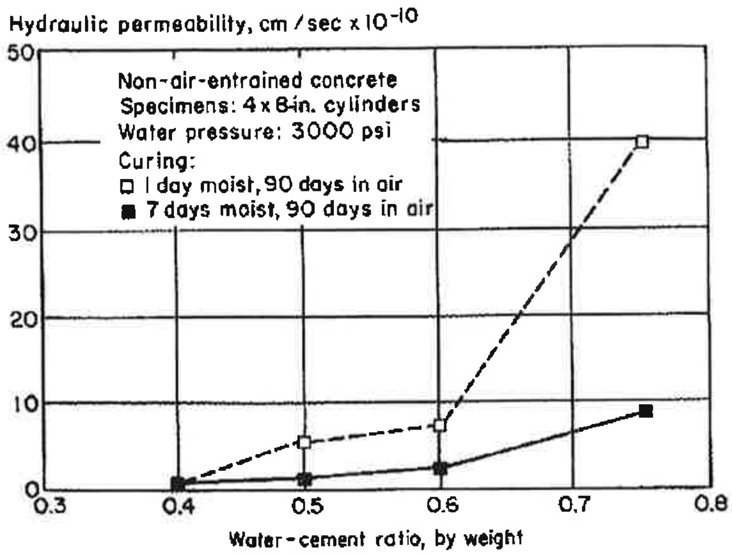

Fig. 1-10. Relationship between hydraulic (water) perm ability, water-cement ratio, and initial curing on concre specimens. Reference PCA HM1170.

Figure 2.2

Figure 2.3 further demonstrates that cure time reduces permeability [1]. In this chart specimens were tested for water leakage through a mortar disc subjected to 20 psi of water pressure. Each curve represents a particular concrete mix. A review of the left most line (water cement ratio of 0.50) shows that the leakage through the disc with a 3 day cure was approximately 0.4 psf per hour. This value is reduced to almost zero for the same specimen that was cured for 7 days.

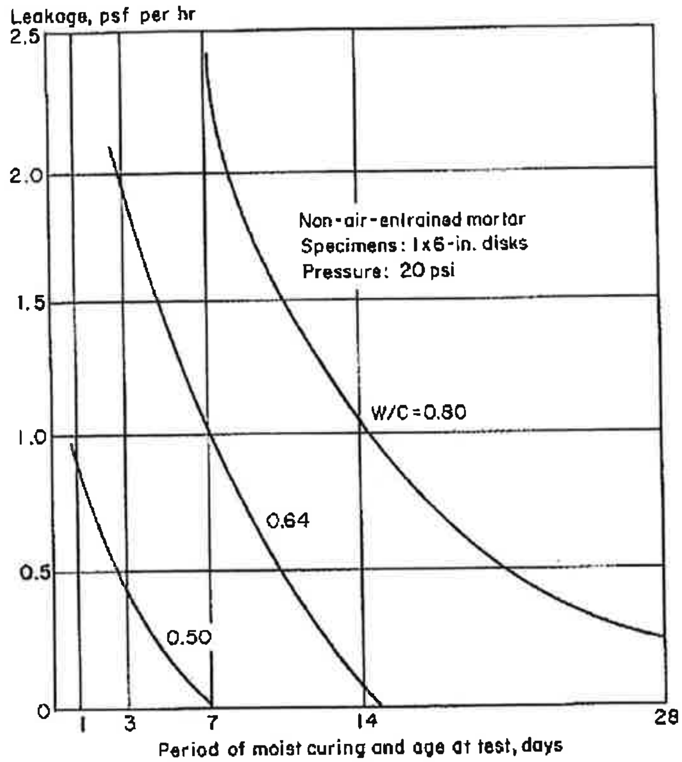

Fig. 1-12. Effect of water-cement ratio (w/c) and curing duration on permeability of mortar. Note that leakage is reduced as the water-cement ratio is decreased and the curing period increased. Reference 1-1 and PCA Major Series 227.

Figure 2.3

- Effect of Cure Time on Concrete Shrinkage Cracking

  There are two basic forms of shrinkage cracking in concrete components. Both are affected by curing methods.

  The first is called plastic shrinkage cracking. This form of cracking is represented by shallow surface cracks along the exposed face of the concrete. This cracking occurs soon after placement and is a result of rapid evaporation of the water near the concrete surface. The water evaporates faster than the internal water can bleed from the concrete. The key to preventing plastic shrinkage cracking is to start the moist curing process as soon as possible after concrete placement.

  The second form of shrinkage cracking is referred to as drying shrinkage. Virtually all concrete mixes shrink as they hydrate. The amount of water used in a concrete mix has the most pronounced affect on the amount of drying shrinkage. As the concrete shrinks, the component changes volume. If the component is restrained (cast in place concrete deck on beams, wall attached to a previously poured footing, etc.) shrinkage cracking can occur which will generate internal tension stresses in the concrete. Concrete is relatively weak in tension. If the internal tension stresses exceed the tensile capacity of the concrete, a crack will develop.

Excessive cracking from shrinkage is detrimental to the concrete structure since it allows an avenue for water to quickly migrate to the level of the internal reinforcing. This water migration can lead to corrosion of the steel. Designers add reinforcing near the concrete surface to control the size of these cracks; however this steel cannot eliminate the cracking.

Curing has a significant impact on drying shrinkage and the potential for shrinkage cracks. A wet cure will delay the onset of the volume change as the concrete cures. Figure 2.4 shows the effect of moist curing on the shrinkage of a typical concrete mix [1]. A review of this chart shows that if the concrete can be kept wet, the start of shrinkage will be delayed. This is an important phenomenon. If the concrete can be kept moist, the mix will gain strength without shrinking. Once the moist curing is removed, the concrete will shrink; however the strength of the mix will help to resist the internal tension stresses caused by shrinkage.

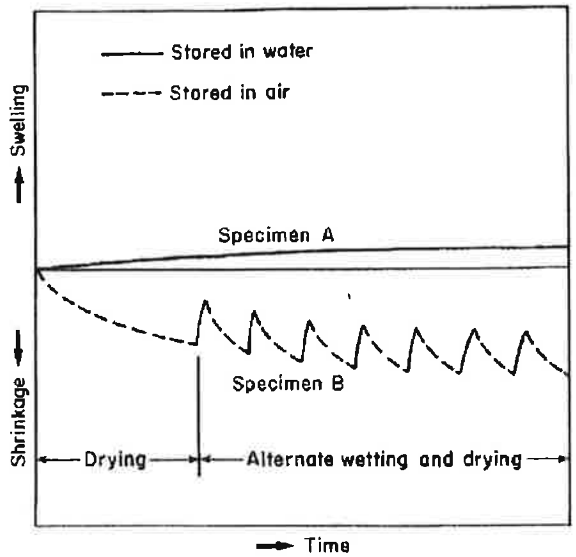

Fig. 13-4. Schematic illustration of moisture movements in concrete. If concrete is kept continuously wet, a slight expansion occurs. However, drying usually takes place, causing shrinkage. Further wetting and drying causes alternate swelling and shrinkage. Reference 13-12.

Figure 2.4

3.0 Use of Precast Concrete and its Effect on Quality

- Water-cement ratio and consolidation:
  The water-cement ratio is simply the weight of water in a mix divided by the weight of the cement in the mix. As demonstrated in Figures 2.2 and 2.3, low water-cement ratio mixes have a significant effect on concrete quality. Low water-cement ratio mixes also produce concretes that have higher strengths when compared to mixes with higher water-cement ratios.

  Concrete mixes with low water-cement ratios (less than 0.45) can be difficult to consolidate. Consolidation is the process of placing concrete without air pockets and voids. Rodding or vibration is often used to help consolidate the mix into the forms. Precast fabrication plants have more sophisticated equipment to consolidate concrete because concrete mixes for precast bridge beams are normally designed with low water-cement ratios. Some fabricators have vibration equipment built into the forms for this purpose.

  Fabricators also have the ability to use add mixtures such as high range water reducing agents (superplasticizers) to make the concrete more workable during casting. These add mixtures can make very stiff concrete flowable and easier to place and consolidate. There is one drawback with these products. The effectiveness of the materials is very short lived. The workability gained by the material dissipates after 30 to 60 minutes. At that time, the mix will stiffen up, to its original condition, which may make proper placement and consolidation difficult if not impossible. This makes use of superplasticizers in field applications very difficult. Delivery time for concrete batch trucks can be sporadic. The materials can be added at the project site, but timing is still very problematic. Use of plasticizers in a fabrication plant is much easier because the delivery of the concrete is normally from an on-site batch plant.

Another new product that is in used in precast fabrication facilities is called self consolidating concrete (SCC). This type of concrete has an add mixture that works in a similar fashion to superplasticizers. It greatly improves the workability of the concrete, which facilitates placement and consolidation. Several precast fabricators that are experienced with the use of SCC have stated that SCC add mixtures are somewhat difficult to work with and are affected by concrete mix variations. Therefore, they should only be used in a controlled environment with high quality concrete batching equipment (such as a precast fabrication plant).

One added benefit of using low water cement ratios is that it may be possible to reduce cure times. Figure 2.2 and 2.3 show that low water cement ratios can minimize permeability [1]. Precast fabricators can produce and place higher strength concretes with very low water cement ratios. The Precast Prestressed Concrete Institute has studied the quality of plant produced precast concrete components and recommends that cure time be limited to 1 to 2 days. This approach can be justified by using lower water-cement ratio concretes.

- Use of Steel forms
  Many precast concrete plants make use of steel forms for casting significant numbers of components. These forms are much more durable than wood forms. There is an added benefit in that the steel side form produces a more dense concrete surface that is also more aesthetically pleasing. When concrete is placed in a wood form, the wood has a tendency to draw moisture out of the concrete mix. This weakens the surface of the concrete. Form oil is often used to minimize this effect; however there is always some loss of moisture. Steel forms will not draw any moisture from the concrete; thereby producing a high quality concrete surface that is very durable.

- Shrinkage cracks (restraint)
  As previously stated in this report, concrete will shrink as it cures. If restrained, the concrete can crack. Restraint on bridge structures can develop in several ways. If any concrete is placed against previously placed concrete, the older concrete will restrain the new concrete and cause differential strains in the two pours, which leads to shrinkage cracking. Examples of this are wall stems cast against footings, and parapets cast

against deck slabs. When cast in place concrete bridge decks are installed on top of steel or concrete beams, the beams restrain the deck, which leads to common transverse deck cracking. This problem is widespread and very difficult to overcome. Every state in the country has problems with shrinkage cracking in bridge decks.

The issue with shrinkage cracking is virtually eliminated when prefabricated concrete components are specified. The precast component are cast separately and allowed to cure in an un-restrained condition, which either eliminates or greatly reduces cracking. At the time of erection of the components, all the concrete has cured and the shrinkage is complete; therefore there is no differential shrinkage between the two components that can lead to cracking. By using prefabricated precast concrete components, shrinkage cracking can be virtually eliminated. Precast concrete full depth decks cast over 18 years ago still do not exhibit any significant cracking, while almost every cast in place concrete deck is riddled with shrinkage cracking.

4.0 Curing Methods

- Types of Curing methods:

  The primary purpose of curing concrete is to retain moisture in the concrete mix until the concrete can gain sufficient strength. The benefits of proper curing were discussed in detail in Section 2 of this report. There are several common types of curing methods used in bridge construction. These range from spray on chemical curing compounds to wet burlap blankets.

  The oldest method of curing concrete is to place wet burlap blankets over the newly placed concrete in order to provide moisture to the concrete surface. This is often supplemented with polyethylene sheeting, which will help to prevent evaporation from the burlap. Another approach is to spray the burlap with fog or sprinklers to keep it moist. This method has proven to be the most useful way to properly cure concrete. There have been many studies into concrete curing in the United States, and wet burlap curing has always proven to be very successful.

  Another way to cure concrete is to apply a chemical compound on the surface of the concrete soon after placement. These compounds retain the moisture in the concrete by forming a barrier to the outside air. In theory, this approach should and can work. Our experience, and the experience of other state DOT's is that they have limited effect in the harsh environment of a bridge construction site. Any disruption of the compound can lead to improper moisture retention. These compounds are also limited by the skill of the person applying the product. It is essential that the compounds be applied uniformly across the surface of the concrete. Another potential issue is the effect of the compound on future toppings and overlays. The compounds may cause improper bonding of overlays and potential failures in the future.

5.0 Conclusions and Recommendations

Based on the information gathered and presented in this report, we offer the following recommendations for the Accelerated Bridge Program at UDOT.

1. All site cast concrete used on UDOT ABC Bridge projects should be cured for a minimum of 7 days. This is recommended to ensure the highest quality of the finished product by minimizing shrinkage cracking and providing lower permeability. If it is not possible to cure site cast concrete for 7 days due to MOT restrictions, low water cement ratios should be used to improve the durability of the concrete. The use of fast cure cast in place concrete should be minimized on ABC projects.
2. Prefabricated concrete components should be specified with low water cement ratios and high strengths in order to improve quality. If this is done, curing can be limited to 1 to 2 days.
3. Prefabricated Components are preferred to site cast concrete components for the following reasons:
    a. Lower water-cement ratio concretes can be used more easily. Superplasticizers and self consolidating concrete can be used more effectively in the in the plant to facilitate placement of the concrete in the forms.
    b. It will be easier to consolidate the concrete in the forms through the use of specialized equipment.
    c. The use of steel forms for repetitive precast components is recommended. This will ensure a high quality product that is aesthetically pleasing.
    d. Construction of individual precast components virtually eliminates shrinkage cracking in bridge structures.
4. Curing of site cast concrete should include the use of wet burlap blankets and polyethylene sheets. This should also be combined with the application of water on a regular basis.
5. Curing compounds should be used sparingly. They should not be used on surfaces that will either be overlaid or topped. If curing compounds are used, they should only be used to cover the concrete during the interim time between placement of concrete and the setting of the wet burlap curing mats.

Submitted by: Michael P. Culmo
VP of Transportation and Structures
CME Associates, Inc.

Date: November 14, 2008

Reference:

[1] Kosmatke & Panarese, Design and Control of Concrete Admixtures, Thirteenth Edition, Portland Cement Association, 5420 Old Orchard Road, Skokie, IL 60077-1083

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